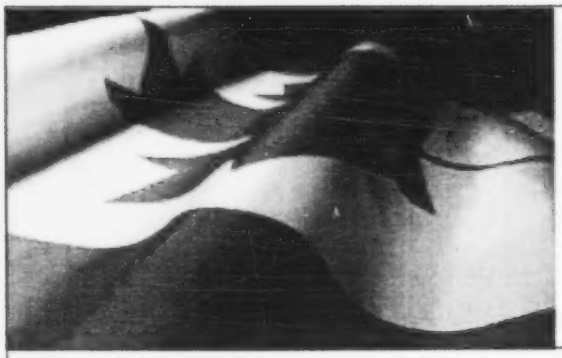

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Machinery & Equipment Investment and Growth: Evidence from the Canadian Manufacturing Sector

by

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Abstract

New Growth Theory points to three potential influences on output and productivity growth – investment in human capital, R&D, and investment in machinery and equipment (M&E). However, much of the literature focuses on human capital and R&D as sources of growth. Few efforts have been made to estimate the impact of M&E investment. This paper presents empirical models that endeavour to fill this gap. Using panel data on 20 Canadian manufacturing industries (1961-1997) and time-series data (1961-2000) for the entire Canadian manufacturing sector, this paper finds that the elasticities of output with respect to M&E capital stock and M&E investment are well above capital's share of national income suggested by a constant-returns-to-scale Cobb-Douglas production function. However, the coefficient on labour is near its income share. The results also suggest that M&E investment is not the only source of growth because the elasticity of output with respect to structures investment is also well above its income share, indicating the possible existence of complementarities between the two types of capital.

Résumé

La Nouvelle théorie de croissance identifie trois sources potentielles qui peuvent influencer la croissance de l'output et de la productivité – l'investissement en capital humain, la recherche et le développement, et l'investissement en machines et matériel. Toutefois, la majorité de la littérature se concentre sur les deux premières sources citées, peu d'efforts ayant été faits pour estimer l'impact de l'investissement en machines et matériel. Cet papier présente des modèles empiriques qui tentent de combler à cette lacune. En utilisant des données de panel pour 20 industries canadiennes (1961-1997) et des séries chronologiques (1961-2000) pour le secteur manufacturier canadien, nous trouvons que les élasticités de l'output par rapport au stock de capital en machines et matériel et à l'investissement en machines et matériel dépasse de loin la part du capital dans le revenu national suggérée par une fonction de production Cobb Douglas à rendements d'échelle constants. Cependant, le coefficient de la main d'œuvre est, lui, près de sa part du revenu. Nos résultats suggèrent également que l'investissement en machines et matériel ne soit pas la seule source de croissance car l'élasticité de l'output par rapport à l'investissement en structures est également bien au-dessus de sa part du revenu, indiquant l'existence possible de complémentarités entre les deux types de capital.

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1. INTRODUCTION

Endogenous growth models, such as those in the pioneering work of Romer (1986) and Lucas (1988) point to three potential influences on long-run productivity growth:

- Investment in human capital;
- Investment in R&D;
- Investment in physical capital, particularly the machinery and equipment (M&E hereafter).

Much of the literature focuses on human capital and R&D as sources of growth. Few efforts have been made to empirically estimate the impact of M&E investment. Delong and Summers (1991) and Sala-i-Martin (1997) provide some econometric evidence using cross-country analysis. Delong and Summers find that increasing the M&E investment share by one percentage point could increase long-run productivity growth by 0.2 to 0.3 percentage points. Sala-i-Martin supports these results. He finds that a one percentage point increase in equipment investment leads to a 0.2 percentage point increase in output growth, while a one-percentage point increase in non-equipment investment leads to only a 0.06 percentage point increase in output growth.

However, there are few studies that focus on individual countries. To our knowledge, the only Canadian study is by Sargent and James (1997). They empirically estimate the effect of physical capital on output growth in Canada, although they do not separate the impact of M&E and structures (non-M&E capital hereafter). Nevertheless, they find that the elasticity of output with respect to aggregate capital is well above capital's share of national income. This result, based on the research by DeLong and Summers, and Sala-i-Martin, can be attributed to the knowledge embodied in M&E investment. However it has yet to be empirically tested for Canada.

If M&E plays a special role in output growth, a key question is why markets do not ensure the socially optimal level of M&E investment. New growth theory suggests that innovation requires large up-front costs (which decrease thereafter due to increasing returns to scale) and firms may be unable to exclusively appropriate the knowledge embodied in the innovation. This leads to low private returns on investment in M&E relative to social returns, which implies sub-optimal investment and growth.

This paper provides empirical evidence in support of this argument for Canada by estimating the impact of M&E and non-M&E investment on output levels. Using both time-series (1961-2000) and panel data (1961-1997) estimation approaches, it finds robust evidence that the coefficient on M&E capital input exceeds its income share in the Canadian manufacturing sector, suggesting that social (aggregate) returns to investment in M&E capital are greater than the private (individual firm) returns, which means that the socially optimal level of investment is higher than the private level of investment.

This paper further finds that both M&E and non-M&E capital stocks and investment affect output and productivity levels more than suggested by a constant-returns-to-scale production function where elasticities are based on factors' income share – a stark contrast to a general belief that M&E investment is the only source of output growth. This result supports Pakko (2002) and Gort *et. al* (1994) who claim that technology successfully transfers from M&E to the non-M&E sector, making non-M&E capital another source of output growth. As well, the result suggests the existence of possible complementarities between the two types of capital, a claim that needs to be tested in a well-defined new growth framework. Output elasticity with respect to labour is at the expected levels, as defined from labour's share of income (about two-thirds for labour).

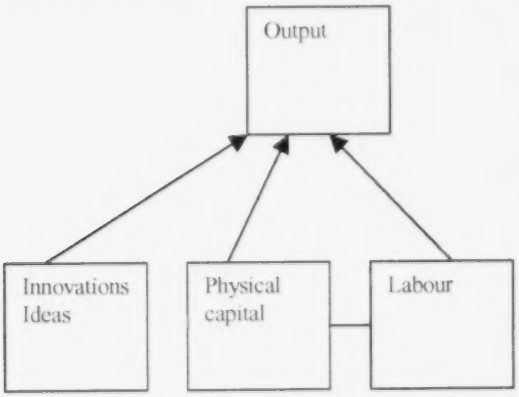
The paper is divided into three sections. Section 2 summarizes the economic growth literature and argues that new growth theory is an appropriate theoretical framework to correctly capture the impact of M&E and non-M&E capital on output, given the theoretical and empirical limitations of neoclassical models. Section 3 explains the model and provides empirical results. Section 4 provides conclusions.

2. GROWTH THEORY AND THE ROLE OF M&E INVESTMENT

The Neoclassical growth theory

The standard neoclassical growth model is based on the work of Solow (1956), which rests on three central assumptions: constant returns to scale, perfect competition and exogenous technological change. In the context of a two-factor Cobb-Douglas production function, these assumptions imply that the sources of growth in output can be decomposed into conventional inputs of labour, physical capital and exogenously determined total factor productivity, which is usually assumed to be related to technological change. As noted in work by Ab Iorwerth (2002), Figure 1 represents a typical neoclassical production function.

Figure 1: A representation of neoclassical growth model



The neoclassical growth model remained at the core of the growth theory for over three decades. However, in the early 1980s many economists began to criticize it on both theoretical and empirical grounds. Perfect competition and constant returns to scale assumptions were called into question as well as the idea that innovation and knowledge

are exogenously determined pure public goods, which can be absorbed by firms at zero cost. Empirically, critics questioned the framework's inability to account for the widespread fall in labour productivity growth in many industrialized countries since the 1970s.[1]

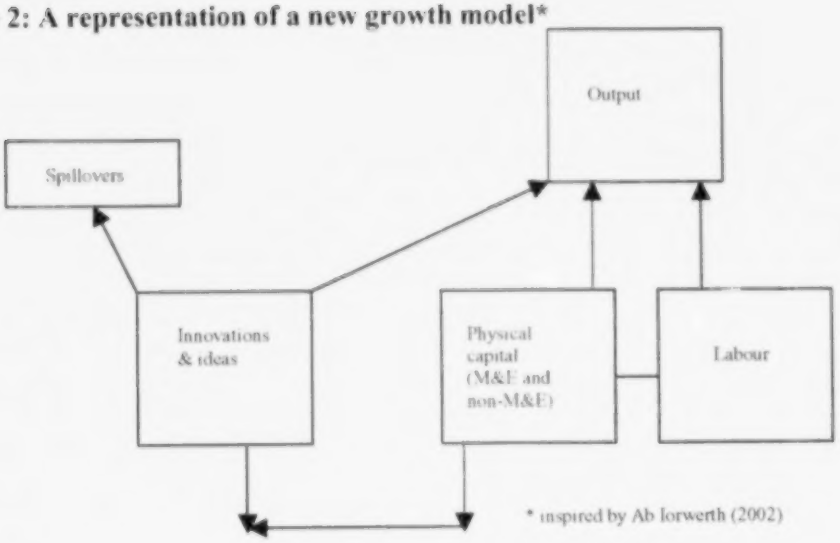
The emergence of new growth theory

Beginning in the early 1980s, many economists began arguing that forces within models should determine the long-run rate of growth, as opposed to those operating outside the model. Nearly a decade of active research on the determinants of long-run growth has generated a rich variety of endogenous growth models.[2] These models fall into two broad categories – models based on physical capital accumulation, and models based on human capital and R&D accumulation. This study focuses only on models based on physical capital accumulation, including those of Romer (1986 and 1987), Barro (1991) and Rebelo (1991). A simple sketch of the new growth model, with two factors of production, is presented below in Figure 2.

[1] See for example, Fortin and Helpman (1995), Sargent and James (1997), Rodrik (1997) and Lucas (1988), for a complete discussion of the empirical shortcomings of the neoclassical model.

[2] For a few examples of the extensive literature on endogenous growth models, see Romer (1990), Grossman and Helpman (1991), Rebelo (1991), Rivera-Batiz and Romer (1991), and Aghion and Howit (1992). Ab Iorwerth (2002), Helpman and Grossman (1994), Barro and Sala-i-Martin (1995), Romer (1996), McCallum (1996), Jones and Manuelli (1997) and Temple (1998) provide good survey of endogenous growth literature.

Figure 2: A representation of a new growth model*



As shown in Figure 2, the new growth model implies that new investment in physical capital embodies new technologies and knowledge that help to generate productivity growth. The model typically assumes that the knowledge embodied in new capital becomes a public good, and therefore has spillover effects on other parts of the economy. As explained in Box 1, this characteristic indicates that firms are unable to capture all the returns on their investment because knowledge creation is not completely exclusive to the firm that creates it. Even if a firm keeps its ideas secret by using patent rights, the production of an innovative product is a signal to other firms that producing such a product is profitable (Ab Iorwerth, 2002).

Moreover, since knowledge is a non-rival product, other firms can take advantage of knowledge-driven products without diminishing the value of the knowledge to the firm doing the investment. Therefore, while investment in capital takes place at the firm level, its full impact is only captured at the aggregate level.[3]

Box 1: Rivalry, Excludability and New Growth Theory

Rivalry: Implies that there is only one consumer of a good. For example, if only one person can drink a cup of coffee then coffee is a rival consumer good. However, the idea of the Internet can be "consumed" by all consumers. Therefore Internet is a non-rival product.

Excludability: Refers to a feature of institutional structure that helps to make consumption excludable. For example, a transistor had patent protection hence its consumption was excludable. Without a license fee it was not possible to procure a transistor. However, the idea of the transistor remained non-rival as other firms could make advances on the transistor because the idea was in the public domain.

New Growth Theory: New growth theory assumes a world of imperfect competition where firms invest to obtain profits. Firms can obtain profits if it is possible to make the products at least partially excludable to prevent others from copying the product. However, since ideas are non-rival, other firms can easily benefit from its spillover effects. In the above example, a patent right can protect the invention of a transistor; however, since the idea is non-rival other inventions can flow from it.

Krugman and Helpman (1993) suggest that:

> ...it is possible to argue that there are external economies resulting from the inability of firms to appropriate knowledge completely. Information gained by one firm, whether explicitly through R&D or through experience, will often be acquired by the firms through word of mouth or deliberate 'reverse engineering'. This is a true externality; however, it is hard to envisage it leading to a relationship [with constant returns]. In the first place innovative industries will ordinarily not be perfectly competitive.

Source: Ab Iorwerth, April 2002, Taxation, Machines, and Economics of Growth, ESPAD, Finance Canada

Existing Empirical Evidence

Researchers have tested new growth models using three econometric techniques -- cross-country regressions, time-series analysis, and panel data estimation. Although each of these techniques has its own limitations, generally speaking they provide evidence in support of a new growth theory. Major empirical results of the three approaches and their principal limitations are summarized below.

[3] In another model, Romer (1987) provides a different mechanism for endogenous growth in which the engine of growth is specialization in capital goods. In this model, there can be diminishing returns to increases in one kind of capital but non-diminishing returns to other types of capital.

(A) Cross-country estimation

Cross-country regressions have been the most popular approach in establishing the association between investment rates and the rate of growth of GDP. Mankiw *et al.* (1992), Romer (1987), Barro (1991), Levine and Renelt (1992), provide cross-sectional evidence in support of a positive relationship between growth and investment rates. However, a major limitation of these studies is that spillovers to other firms and industries cannot be captured in these cross-country studies.[4] In light of this limitation, economists started testing growth models using time-series and panel data estimation approaches.

(B) Time-series analysis

There is a small but growing number of studies that use time-series analysis to estimate new growth models, improving on cross-country analyses by capturing growth patterns of individual economies over time. The most recent examples are studies by Coe and Helpman (1995), Brecher et al. (1996), McGratten (1998), and Li (1998) whose results strongly support the predictions of new growth models.

Although most time-series evidence is supportive, there has been some debate in the literature. For example, Young (1992) used time-series data from Hong Kong and Singapore, but did not find a significant positive relationship between investment and economic growth. As well, Jones (1995) found that the time-series evidence from selected OECD countries rejects many new growth type models.[5] However, Jones' results were strongly criticized by Li (1998), who used the recently updated Summers and Heston (1991) Penn World Table (Mark 5.6) as the main data source, instead of Penn World Table (Mark 5) used by Jones. Using this improved data set, Li's results were very supportive of new growth models.

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[4] See, for example, Li (1998) for a detailed discussion on this issue.

(C) Panel-data estimation

A number of researchers find that the properties of new growth theory, particularly the relationship between investment rates and growth, hold empirically with the panel data approach. Because panel data comprise observations of a cross-section of units (countries or firms) over time, they provide greater variability, more degrees of freedom, and less collinearity among variables than single time-series data sets. Coe and Helpman (1995), Islam (1995), Evenson and Singh (1997), and Li (1998) have employed this approach in estimating new growth models and obtained very supportive results.

In line with recent attempts, this paper also employs both the time-series and panel data estimation approaches in estimating the implications of the new growth theory for the Canadian manufacturing sector.

Role of M&E

Fairly recently, economists have started examining the relationship between capital and growth by disaggregating capital into its broader categories - M&E and non-M&E capital. For example, DeLong and Summers (1991, 1992) found a strong link between equipment investment and economic growth. Sala-i-Martin (1997) supported their view and found that the impact of M&E investment on output growth was about four times higher than the impact of non-M&E capital investment.

However, further empirical support for these findings has been mixed. Auerbach, Hassett, and Oliner (1999) used the subset of DeLong and Summers' data to examine the empirical link between investment and growth in OECD countries (contrary to DeLong and Summers' work which included developing countries as well) and found that returns to investment in equipment and structures were fully consistent with the neoclassical growth model. Moreover, they found that the coefficient on structures was twice the sign of the coefficient on machinery and equipment for OECD countries.

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[5] Jones (1995) also showed that during 1950-88, investment rates in many OECD countries accelerated but growth rates trended down over the same period. Individual countries regressions showed little evidence on the association between investment and output growth.

Other studies have also supported the view that non-M&E investment is an important contributor to economic growth. Gort, Greenwood and Rupert (1994) found evidence of a significant technological advancement in U.S. structures over the 1988 to 1996 period. Specifically, the rate of technological progress in structures was found to be about 1.8% per year over this period, accounting for about 32% of economic growth in the U.S.[6] Pakko (2002) supported these findings and indicated that new technology that is embodied in the M&E capital transfers to the non-M&E capital, making non-M&E another source of output growth.

The on-going discussion of the impact of different types of capital on output growth suggests that we need to investigate not only whether physical investment plays a special role for long-term growth in Canada, but whether the type of capital investment also matters. This paper helps to fill this research gap by disaggregating capital into two broad categories – M&E capital and non-M&E capital.

Evidence for Canada

As mentioned earlier, there is currently little evidence on the relationship between investment in capital and output growth in a new growth framework for Canada. The only study of which we are aware is Sargent and James (1997) who estimate the elasticity of output with respect to physical capital, but do not explicitly estimate output elasticity with respect to M&E investment. They find that the elasticity of output with respect to capital is close to one, much greater than that suggested by its income share.

Several other Canadian studies have pointed to the particular importance of M&E investment for growth. For example, Fortin (1999) argues that under-investment in M&E in Canada relative to the United States is the principal reason for a growing productivity gap between Canada and the United States. Rodriguez and Sargent (2001) support this

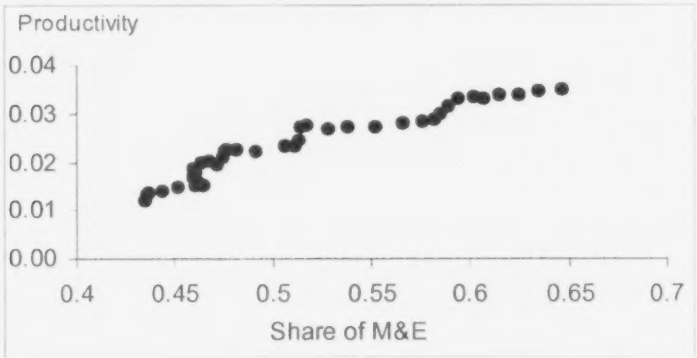
[6] This study employs a general equilibrium approach to growth accounting, which is significantly different than a conventional growth accounting framework. The general equilibrium approach taken in this study allows for the growth in output due to capital accumulation to be broken down to its underlying sources of technological progress. This is in contrast to a conventional growth accounting practice that uses an aggregate production function to decompose output growth into technological progress and changes in inputs.

view, noting that in 1999 investment in M&E was almost 50% lower in Canada than in the U.S. and this gap has been long standing, particularly when measured in terms of M&E capital stock per worker.[7]

Casual observation of data from the Canadian manufacturing sector in Figure 3 suggests a strong relationship between M&E and productivity growth. Indeed, the correlation coefficient between the share of M&E capital stock in total physical capital and the level of average labour productivity is 0.96. Figure 4 maps this relationship at the industry level showing that the correlation is widespread across different sectors of the economy. As discussed, this relationship is not expected under a neoclassical growth framework.

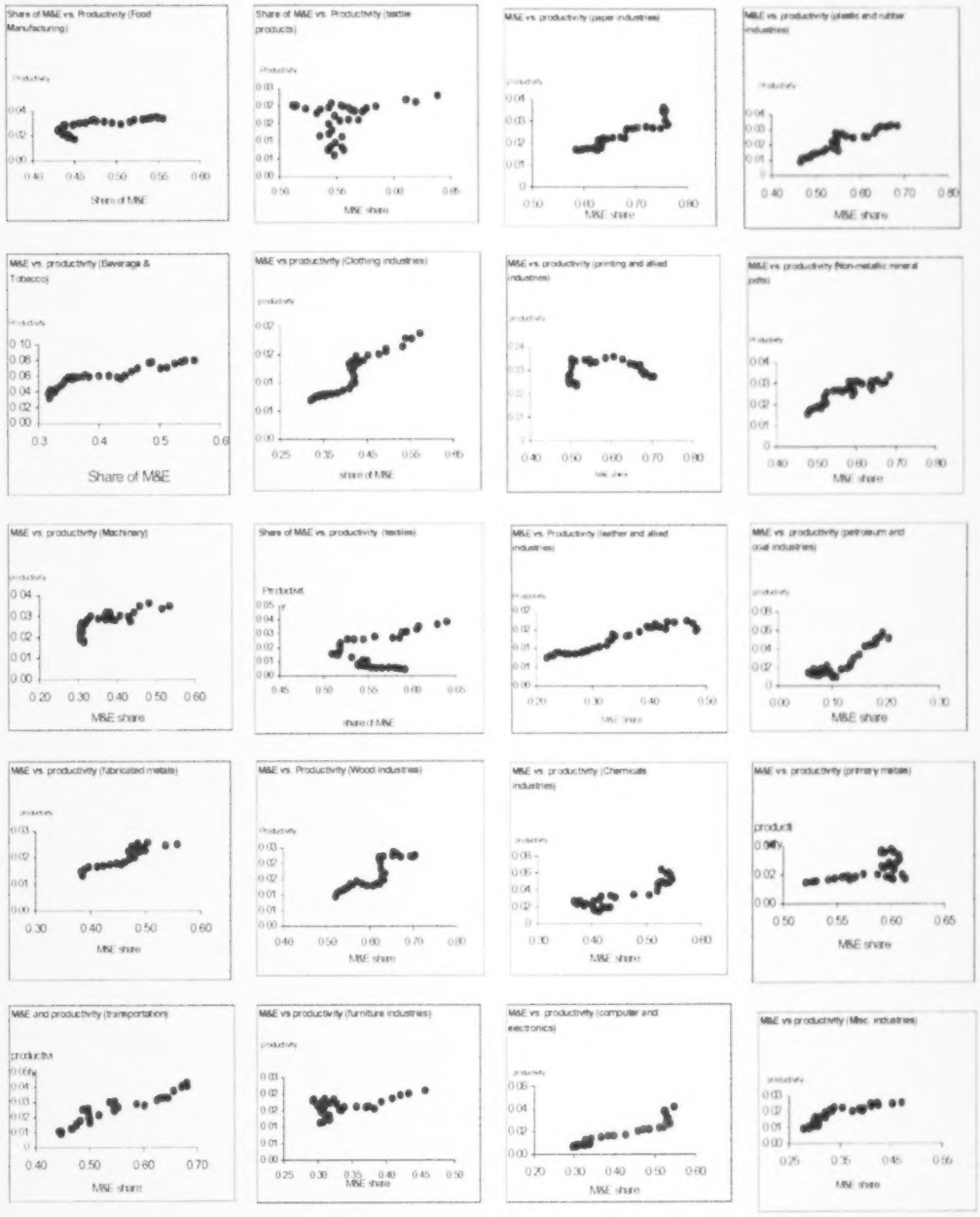
The next section provides an empirical test of whether in fact the new growth argument is supported by Canadian data.

Figure 3: Share of M&E Capital Stock in Total Capital Stock and Average Labour Productivity



[7] A number of studies have used a growth accounting framework to illustrate the impact of M&E and ICT investment on Canadian productivity growth. For example, see Armstrong, Harchaoui, Jackson and Tarkhani (2002), Jorgenson, Ho and Stiroh (2002), Jorgenson (2000), Rao, St-Jacques and Tang (2001), Baldwin and Harchaoui (2001), and Gera, Gu and Lee (1999).

Figure 4: Share of M&E Capital Stock and Average Labour Productivity Across Manufacturing Industries


Share of M&E vs. Productivity (Food Manufacturing)
Share of M&E
Share of M&E vs. Productivity (textile products)
M&E share
M&E vs. productivity (paper industries)
M&E share
M&E vs. productivity (plastic and rubber industries)
M&E share
M&E vs. productivity (Beverage & Tobacco)
Share of M&E
M&E vs productivity (Clothing industries)
share of M&E
M&E vs. productivity (printing and allied industries)
M&E vs. productivity (Non-metallic mineral prds)
M&E share
M&E vs. productivity (Machinery)
M&E share
Share of M&E vs. productivity (textiles)
share of M&E
M&E vs. Productivity (leather and allied industries)
M&E vs. productivity (petroleum and coal industries)
M&E share
M&E vs. productivity (fabricated metals)
M&E share
M&E vs. Productivity (Wood industries)
M&E share
M&E vs. productivity (Chemicals industries)
M&E share
M&E vs. productivity (primary metals)
M&E share
M&E and productivity (transportation)
M&E share
M&E vs productivity (furniture industries)
M&E share
M&E vs. productivity (computer and electronics)
M&E share
M&E vs productivity (Misc. industries)
M&E share

3. A NEW GROWTH MODEL

Theoretical framework

Assume that output depends on three inputs – M&E capital, non-M&E capital and labour. All firms have identical and constant-returns-to-scale technologies. Markets are perfectly competitive and factors of production are perfectly mobile between sectors. At the firm level, the production function can be written as:

$$Y = A \cdot F(K_1^a K_2^b L^c) \qquad (1),$$

where Y is the real output, K_1 and K_2 are respectively M&E and non-M&E capital inputs, L is the labour input and A, a scaling variable. Coefficients a, b, and c represent, respectively, the share of M&E capital, non-M&E capital and labour inputs in total output.[8]

Assume that the M&E capital stock used by the firm embodies productivity-enhancing knowledge. As well, it is possible that the gains from investment cannot be fully captured by the firm that makes the investment. In this case, all firms benefit from a single firm's investment and the social return to investment exceeds the private return. Consequently, at the aggregate level, the term A becomes a function of M&E capital so that:

$$A = B \cdot K_1^d$$

[8] For simplicity, this model assumes a Cobb-Douglas production function; however, while the use of any other function, such as a Constant Elasticity Substitution (CES) production function, might change the quantitative results, the qualitative analysis here would likely be largely unaltered.

The industry production function then takes the form[9]

$$Y_t = B\, K_1^{\delta}\, K_2^{b}\, L^{c} \qquad (2),$$

where we would expect $(\delta + b + c) > 1$, $a = 1-(b+c)$, and d (the knowledge component of K) equals to $\delta - a$.

Alternatively, the impact of M&E investment, non-M&E investment and the change in the labour input can also be written as follows.[10]

$$Y_t = A\,.\,K_{1t}^{a}\, K_{2t}^{b}\, L_t^{c} \qquad (3),$$

with

$$A = G\,(I_t^{d}\, N_t^{e}) \qquad (4),$$

where I, and N represent respectively investment in M&E and non-M&E capital.

Due to very strong multicolinearity between additional capital (i.e. new investment) and capital stock, it is econometrically inefficient to estimate coefficients for M&E investment and capital stock in the same equation. Instead, using factor income shares we calculate $A\,(\equiv \frac{Y_t}{K_{1t}^{a} K_{2t}^{b} L_t^{c}})$ and then estimate the impact of M&E investment (I) and non-M&E investment (N) on A.[11]

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[9] Since the production function is linearly homogenous of degree 1, it can be written as $y_{it} = B\, k_{1it}^{\delta}\, k_{2it}^{b}$ where $k_1\,(\equiv \frac{K_1}{L})$ is the M&E capital-labour ratio, $k_2\,(\equiv \frac{K_2}{L})$ is the non-M&E capital-labour ratio, $\delta = (a+d)$ and B is a constant term. Econometric results for this type of model are reported in the appendix.

[10] Romer (1986) suggests that it is only new investment that embodies new knowledge capable of increasing productivity. In this case, the term A becomes a function of the knowledge component of M&E investment, non-M&E investment and addition to labour hours.

[11] Coe and Helpman (1995) used similar method in estimating spillover effects of international trade.

Data

This study uses time-series and panel data sets over the 1961 and 2001 period to estimate the effect of different types of capital investment on output growth in a new growth theory framework. Net capital stocks of M&E and non-M&E are constructed using hyperbolic depreciation rates. The capital stock in use is obtained by multiplying the hyperbolic net capital stock of each industry with the corresponding industrial capacity utilization rates. Net capital stock data are from Statistics Canada's Fixed Capital and Stock Survey. Output is measured using manufacturing value-added data (at 1992 prices) and labour input is measured by actual hours worked. Both data series are obtained from Statistics Canada and pertain to the business sector.

For the panel estimation, we have data on capital, output, and labour input for 20 manufacturing industries. Data on capital stock are available for industries at the 2-digit level of the North American Industrial Classification System (NAICS), while data for value added and hours worked are available under the Standard Industrial Classification (SIC) system mainly at the three digit level. While the two classifications differ somewhat in the grouping of particular industries, Sharpe (2002) notes that as long as growth rates across the industries are the same, the available data from the two distinct classifications can be used for estimation.[12]

Empirical Analysis

Time-series Analysis

The first step of the empirical analysis is to estimate equation (2) using aggregate time-series data for the Canadian manufacturing industries. To test if the data series were stationary or integrated, we use ADF test t-statistics for the null hypothesis of non-stationarity in level and first difference form for capital stock of M&E and non-M&E (i.e. K_1 and K_2), capacity adjusted capital stock of M&E and non-M&E (i.e. KS_1 and KS_2), M&E investment (I), non-M&E investment (N), labour hours (L), and the output

[12] See the data appendix for additional details and caveats about the data.

(Y). We find that all the series are difference stationary but not level stationary, and the variables are integrated of order 1. Since we want to estimate the production function in level form, we test for co-integrating relationships among the variables. The results are supportive of the hypothesis of at most one co-integrating equation in every case, implying that the regression can be estimated in level form using a Vector-Error-Correction (VEC) methodology.[13]

We first estimate equation (2) using net capital stock data for M&E and non-M&E variables and labour hours. We assume that the stock of capital accumulated at time *t-1* is available for use in the next period (time *t*), therefore we lag both the M&E and non-M&E capital stock by one period. Equation (2) is then estimated in the following form:

$$\ln Y_t = B + \delta \ln K_{1t-1} + b \ln K_{2t-1} + c \ln L_t + \varepsilon_t \qquad (5),$$

where $\delta = (a + d) > 0$, $b > 0$ and $c > 0$.

One limitation of estimating (5) is that the data reflects the stocks but not the actual use of capital. Thus we re-estimate equation (5) by employing capacity adjusted capital stock data. These data series are obtained by multiplying net capital stock by the industrial capacity utilization rates. The equation is estimated in the following form:

$$\ln Y_t = B + \delta \ln KS_{1t} + b \ln KS_{2t} + c \ln L_t + \varepsilon_t \qquad (6),$$

where KS_1, and KS_2 represents respectively the M&E and non-M&E capacity-adjusted capital at time t.

[13] ADF and co-integration test results are reported in the Appendix. A VEC model is designed for use with non-stationary series that are known to be co-integrated. Generally speaking, the VEC specification restricts the long-run behaviour of the endogenous variables to converge to their co-integrating relationships while allowing for short-run dynamics.

Estimations for equations (5) and (6) are reported in the second and third columns of Table 1. The sum of the long-run coefficients is significantly above 1 in both cases -- 1.56 in the case of net capital stock and 1.45 in the case of capacity-adjusted capital stock -- suggesting that the constant-returns-to-scale assumption of the neoclassical model might not hold.[14]

Table 1: Time-series Regression Results (t-statistics are reported in parenthesis)

Variables	(a) Capital stock data (Equation 5)	(b) Capacity-adjusted capital data (Equation 6)	(c) K1, K2 and L imposed from CEFM (Equation 7)
Log (K1)	0.67**	--	**0.21**
	(14.17)		
Log (K2)	0.24**	--	**0.12**
	(3.43)		
Log (KS1)	--	0.47**	--
		(8.59)	
Log (KS2)	--	0.19*	--
		(1.66)	
Log (L)	0.65**	0.79**	**0.67**
	(4.51)	(4.27)	
Log (I)	--		0.20**
			(10.36)
Log (N)			0.23**
			(2.24)
Constant			-4.74
	-8.45	-7.87	
R2	**0.17**	**0.34**	**0.53**

**Significant at 1%, *Significant at 10%. (a) K1 and K2 lagged 1 period. (b) KS1 is lagged 1 period.

Furthermore, the M&E coefficients are high and significant in both regressions, 0.67 in case of capital stock data (column a) and 0.47 in case of capacity-adjusted capital data (column b). This compares to an income share estimate of about 0.2 for M&E capital. The coefficient estimates on non-M&E, 0.24 in column (a) and 0.19 in column (b), are also above their income share of 0.13. However, the coefficient estimates of labour, 0.65 in column (a) and 0.79 in column (b), are close to its income share of 0.67.

[14] While the sum of estimated coefficients noted in Table 1 might seem unrealistically for the economy as a whole (between 1.56 and 1.45) these estimates are more realistic for only the manufacturing sector

The importance of both M&E and non-M&E capital to output is also evident from equation (7), which is a log linear approximation of equation (4). This equation directly tests the impact of M&E and non-M&E capital investment on TFP levels as follows:

$$\ln A = G + d \ln I_t + e \ln N_t + \varepsilon_t \qquad (7),$$

where a, *b* and *c* are the factor income shares, and we would expect that d > 0, and e > 0. Column (c) of Table 1 shows high and statistically significant coefficients for M&E investment and non-M&E investment, 0.20 for M&E and 0.23 for non-M&E. This means that doubling M&E investment could raise TFP levels by 20% and doubling non-M&E investment could increase TFP by 23%.

Panel Data Tests

Now we re-estimate equation (2) using panel data from 20 manufacturing industries. First we estimate equation (2) in first-difference form to examine short-run relationships:

$$\ln(Y_t - Y_{t-1}) = B_i + \delta \ln(K_{1t} - K_{1t-1}) + b \ln(K_{2t} - K_{2t-1}) + c \ln(L_t - L_{t-1}) + \varepsilon_t \qquad (8),$$

where *B* is a fixed effect industry dummy. As in the time-series case, equation (8) is estimated using two types of capital data series (net capital stock and capacity-adjusted data series). The results are reported in columns (2) and (3) of Table 2.

In the short-run, the elasticity of output with respect to capital (i.e. M&E and non-M&E capital) is statistically insignificant. This is true in the case of both measures of capital. However, the coefficients for labour are very high and significant (1.01 in the case of net capital stock and 1.03 in case of the capital service estimation), indicating that in the short run differences in output among industries largely reflect variations in labour inputs as capital is effectively fixed.

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estimated here. This is because manufacturing industries are much more likely to display increasing-

Table 2: Results of Panel Data Regressions (Fixed Effects)

Variables	Short-run Relationship (First difference)		Long-run Relationship (Newey-West method)	
	Capital stock data	Capacity-adjusted capital data	Capital stock data	Capacity-adjusted capital data
Log (K1)	-0.133 (-1.306)	--	0.422• (5.186)	--
Log (K2)	0.087 (0.798)	--	0.535• (3.430)	--
Log (KS1)	--	-0.044 (-1.036)	--	0.380• (5.479)
Log (KS2)	--	0.296 (0.539)	--	0.625• (4.593)
Log (L)	1.009• (12.969)	1.026• (25.988)	0.153 (1.181)	0.023 (0.1889)
Food	0.02	0.018	-0.80	0.664
Beverages & Tobacco	0.03•	0.025	-0.69	0.530
Textile Products	0.04•	-0.035	-0.17	1.323
Textile Mills	0.06•	0.015	-1.53	-0.195
Clothing	0.03•	-0.022	0.18	1.704
Leather & Allied	0.02•	-0.005	-0.29	1.034
Wood Products	0.03•	0.012	-1.26	0.194
Paper Products	0.003	0.014	-1.51	-0.767
Printing & Related	0.01	-0.009	0.58	2.064
Petroleum & Coal	0.05•	0.018	-3.07•	-2.031
Chemicals	0.04•	0.006	-1.78	-0.475
Plastic & Rubber	0.04•	-0.019	-1.14	0.243
Non-Metallic Mineral	0.02•	0.001	-1.28	0.173
Primary Metals	0.03•	0.003	-2.23	-0.906
Fabricated Metals	0.003	-0.013	-0.09	0.976
Machinery	002	0.010	-0.40	1.012
Computer, Electric & Electronic Products	0.06•	0.005	-0.29	1.205
Transportation Mfg.	0.05•	-0.032	-1.09	0.464
Furniture & Related Product	0.02	0.015	-0.11	1.299
Miscellaneous	0.03•	0.005	0.52	1.961
R2	**0.44**	**0.50**	**0.96**	**0.97**

Significant at 1%. t-statistics are in parenthesis. KS1 & KS2 lagged one period.

returns-to-scale than the services which comprise more than half the economy.

We now examine the long-term relationship and re-estimate equation (8) as follows:

$$\ln Y_t = B_t + \delta \ln K_{1t} + b \ln K_{2t} + c \ln L_t + \varepsilon_t \qquad (9),$$

The econometric results of equation (9) are reported in the last two columns of Table 2.[15]

In the long run, both the M&E and non-M&E capital elasticities are high and significant, suggesting that output levels over the long run could mainly be driven by investment in physical capital. However, there is a statistically significant difference between the effect of the two types of capital on output, where non-M&E capital has the strongest impact. This suggests that structures can directly embody new technology and facilitate the introduction of new ideas as or even more effectively than M&E.[16]

As well, in the long run estimation, there is mixed evidence in support of new growth theory. On one hand, led by an insignificant coefficient on labour, the sum of the elasticities for the three factor inputs (M&E, non-M&E, and labour) is not significantly different from 1, suggesting that the assumptions of neoclassical theory may hold. On the other hand, coefficients on M&E and non-M&E capital are significantly higher than their income share, which is consistent with the predictions of new growth theory.

This apparent contradiction in the panel data results may be attributable to two factors: (1) the labour data are not adjusted for quality and (2) the results are sensitive to the data chosen as a proxy for labour input.

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[15] The error term in (9) could be heteroskedastic and auto-correlated. To guard against these concerns, we use the Newey-West (1987) procedure to obtain heteroskedasticity and auto-correlation consistent estimates of standard errors.

[16] For example, big stores, such as Walmart, can generate various efficiencies that directly impact the output and productivity growth of the economy.

(1) Quality adjustments: Generally speaking, an hour of work by a skilled worker should not be equivalent to an hour worked by an unskilled worker, since the output per hour of a skilled worker is usually higher than that of an unskilled worker. This suggests that the total number of work-hours recorded would be higher if labour data were adjusted for quality differences. Moreover, Fuente and Doménech (2000) suggest that the negative impact of labour quality is usually more profound in panel-data estimations, particularly in fixed-effect models, than in cross-section models, as the latter approach relies heavily on both the time-series and cross-section variation of the data. Taken together, failure to incorporate quality adjustments could yield an insignificant labour impact in a growth equation, particularly in the fixed-effect estimation.

(2) Choice of Data: As described by Sargent and James (1997), the significance of the coefficient on labour is sensitive to the choice of data series (i.e. hours worked or total persons employed). In particular, the authors find an insignificant labour coefficient of 0.22 when hours worked are used, but when they use the number of workers employed, results generate a significant coefficient of 0.67. Thus, the use of hours worked as a proxy for labour input in this study could have led to the insignificant labour coefficient.

However, the precise cause of the insignificant labour coefficient in the panel-data estimation remains an area for further investigation and research.

Interpretation of results

In summary, our results suggest that both M&E and non-M&E investment could affect long-term growth by more than that suggested by a neoclassical constant-returns-to-scale production function. Using both time-series and panel-data estimation, our estimated coefficients on M&E and non-M&E capital are significant and greater than their income shares, suggesting that social (aggregate) returns to M&E and non-M&E capital in Canada are larger than private (individual firm) returns.

Overall, our results support Sargent and James (1997), who also find that physical capital plays a special role in long-term growth in Canada. Yet, contrary to the results of

Sala-i-Martin (1997) and DeLong and Summers (1991) we do not find enough evidence that M&E investment is the only source of raising output levels in Canada. Rather, we find that both types of capital matter. Therefore, we support Gort *et al.* (1999) and Pakko (2002) who find that new technology, which is embodied in M&E investment, transfers to structures and contributes to growth.[17] In fact, in our panel estimation of the impact of non-M&E capital has a larger effect than M&E capital, a result similar to that found by Auerbach et al. (1994) for all OECD countries.[18],

[17] However, this could further suggest that the strong effect of non-M&E capital is actually representing the effect of the M&E capital on output. Therefore it is important to correctly estimate the extent by which transfer of technology from M&E makes non-M&E a contributor to growth.

[18] Auerbach et al. find that the non-M&E coefficient is larger but that the sum of M&E and non-M&E investment coefficients are the same as that suggested by a neoclassical Cobb-Douglas production function with constant-returns-to-scale, which is not consistent with our study.

4. CONCLUSION

Our results are consistent with the notion that the inability of firms to exclusively appropriate the knowledge embodied in innovations may lead to sub-optimal investment and growth in Canada.

However, contrary to an assumption that new technology is embodied only in M&E investment, our results suggest that both M&E and non-M&E capital stock and investment could affect output and productivity levels more than suggested by a constant-returns-to-scale Cobb-Douglas production function.

- Based on time-series analysis M&E capital stock (at coefficient of 0.67), is relatively more important in raising output levels than non-M&E capital. However, the coefficient of non-M&E capital (0.24) remains above its income share of 0.13, suggesting that capital investment as whole could have external effects on output. The elasticity of output with respect to labour is about at the expected level as defined by labour's share of income (about two-thirds for labour).
- The estimation that directly tests the impact of M&E and non-M&E investment on TFP levels also points to the importance of capital investment at the aggregate level, suggesting that doubling the M&E investment could raise the TFP levels by about 20% and doubling non-M&E investment could raise the TFP levels by almost 23%.
- Although, non-M&E capital has a larger effect on output than M&E capital in panel estimation, the coefficient for M&E capital remains above its share of income of about 0.20.

The empirical work could be usefully extended in several directions. First, we need to examine the process through which technology in M&E investment transfers to the non-M&E sector. Second, human and ICT capital could be incorporated in the production

function. Third, the model could be applied to estimate the determinants of the productivity growth gap between United States and Canada. The theoretical framework, with two-factors neoclassical growth model for such estimation is outlined in Rodriguez and Sargent (2001), which could easily be extended in a three-factor-two-country endogenous-growth-framework.

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APPENDIX

Data Details

This study uses data on the net capital stocks of M&E and non-M&E constructed using hyperbolic depreciation rates. Generally speaking, a straight-line or linear depreciation method assumes equal dollar depreciation over the life of an asset. A geometric depreciation method, on the other hand, assumes higher dollar depreciation in the early years of an asset's service life than in later years, while the hyperbolic method assumes a slower depreciation in the beginning of asset's life than in later years. Statistics Canada provides estimates for all three types of net capital stocks. This study follows the common practice of using the hyperbolic method to estimate capital series. The United States Bureau of Labour Statistics (BLS) and the Australian Bureau of Statistics use this method. We also use gross stock of M&E and non-M&E capital stocks. The gross stock of capital is simply the sum of the past history of gross investment in constant prices, less the sum of losses due to accidents, scrapping and disposables.[19]

It is important to distinguish between the quantity of capital stock and the capital stock in use. One solution to this problem is to use capital services data series yielded by net or gross capital stock. Statistics Canada has recently introduced a method for estimating the growth of capital services, which is appropriate for an aggregate production function analysis. This methodology is outlined in Harchaoui and Tarkhani (2002). The procedure involves estimating the real investment flows at detailed asset class to estimate capital stock for each asset class at the industry level. It then estimates the user cost of capital for each industry to derive rates of return at the industry level. The growth rates of the stock of capital by asset type of individual industries are then aggregated, using the user cost of capital to derive an estimate of the growth in the flow of capital services by industry. Unfortunately, the data on capital services is not yet publicly available. Therefore, we measure capital stock in service by multiplying the net capital stock data series of each industry with the corresponding industrial capacity utilization rates.

[19] See for example, Barbara Fraumeni (1997) and Ariel Coremberg (2002) and Lysko (1995) for a detailed discussion on the methods to compute depreciation rates.

Actual hours worked data are used as labour input. One limitation of labour data is that it sums all hours worked across all workers, but does not account for differences in skills of different workers. This could mean that the impact of skilled workers on output and productivity growth is similar to that of unskilled workers, which is incorrect. Nevertheless, the lack of differentiation between skill levels of workers is unlikely to be very serious, since the proportion of skilled entrants into the labour market is small relative to the total stock of workers. However, if the growth of skilled entrants is strongly correlated with the growth in hours worked, the estimated labour coefficient for unskilled workers may be overestimated.

Appendix Table 1: Unit Root Tests

Variables	Level is non-stationary	Difference is non-stationary
Log(Y)	-1.427798	-4.410767*
Log(K1)	-1.485499	-4.924492*
Log(K2)	-1.350897	-5.355314*
Log(KS1)	-1.435245	-4.879740*
Log(KS2)	-3.038261	-4.426439*
Log(L)	-3.074917	-3.370104*
Log(I)	-1.204955	-5.792003*
Log(N)	-5.211320*	-5.839995*
Critical Values		
1%	-3.6117	-3.6171
5%	-2.9399	-2.9422
10%	-2.6080	-2.6092

*All series have at least one unit root at 5% significance level. Data are annual 1961-2000. Test equation includes an intercept.

Appendix Table 2a: Co-integration Test Results Measure 1 (Capital Stock)

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
(a) Regressors: log (K1), log (K2), and log (L)				
0.759003	77.92852	47.21	54.46	None **
0.403271	28.12448	29.68	35.65	At most 1
0.239479	10.05423	15.41	20.04	At most 2
0.013421	0.472911	3.76	6.65	At most 3
(b) Regressors: Log (I), and Log (N)				
0.518244	37.85484	29.68	35.65	None **
0.246747	10.83310	15.41	20.04	At most 1
0.009388	0.348994	3.76	6.65	At most 2

Appendix Table 2b: Co-integration Test Results Measure 2 (Capital Service)

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
Regressors: log(KS1), log(KS2), and log(L)				
0.670893	82.54358	62.99	70.05	None **
0.476343	41.42276	42.44	48.45	At most 1
0.294117	17.48680	25.32	30.45	At most 2
0.116895	4.599505	12.25	16.26	At most 3

Note: LR. test indicates 1 co-integrating equation at 5% significance level, lagged one period. Test assumption includes an intercept (no trend) in CE and test VAR.

Appendix Table 3: Estimation Results of Equation 5

Cointegrating Equation	**Cointegrating equation 1**
Log(Y(-1))	1.00
Log(K1(-2))	-0.67 (-14.17)
Log(K2(-2))	-0.24 (-3.43)
Log(L(-1))	-0.65 (-0.65)
Constant	8.45
Error Correction	**D(log(Y))**
Cointegrating equation	-0.47 (-1.92)
D(log(Y(-1)))	-0.04 (-0.14)
D(log(K1(-2)))	-0.96 (-1.73)
D(log(K2(-2)))	1.91 (2.23)
D(log(L(-1)))	0.83 (1.56)
Constant	0.03 (1.43)
R-Squared	0.17
Adjusted R-Squared	0.04

Appendix Table 4: Estimation Results of Equation 6

Cointegrating Equation	**Cointegrating equation 1**
Log(Y(-1))	1.00
Log(KS1(-2))	-0.47
	(-8.59)
Log(KS2(-2))	-0.19
	(-1.66)
Log(L(-1))	-0.79
	(-4.27)
Constant	7.87
Error Correction	**D(log(Y))**
Cointegrating equation	-0.35
	(-1.53)
D(log(Y(-1)))	0.65
	(0.81)
D(log(Y(-2)))	0.42
	(0.62)
D(log(KS1(-2)))	-0.84
	(-1.18)
D(log(KS1(-3)))	-0.23
	(-0.76)
D(log(KS2(-1)))	-1.27
	(-2.02)
D(log(KS2(-2))	0.41
	(0.52)
D(log(L(-1)))	0.97
	(1.26)
D(log(L(-2)))	-1.08
	(-1.73)
Constant	0.06
	(1.79)
R-Squared	0.34
Adjusted R-Squared	0.11

Appendix Table 5: Estimation Results of Equation 7

Cointegrating Equation	**Cointegrating equation 1**
A(-1))	1.00
Log(IM(-1))	-0.20
	(-10.36)
Log(IN(-1))	-0.23
	(-2.24)
Constant	-4.74
Error Correction	**D(A)**
Cointegrating equation	0.14
	(2.7)
D(A(-1))	-0.44
	(-2.18)
D(A(-2))	-0.35
	(-1.85)
D(log(IM(-1)))	-0.04
	(-1.88)
D(log(IM(-2)))	0.01
	(0.31)
D(log(IN(-2)))	-0.004
	(-0.21)
D(log(LN(-2)))	-0.01
	(-0.46)
Constant	0.01
	(4.32)
R-Squared	0.44
Adjusted R-Squared	0.35

Appendix Table 6: Estimation Results of Model $y_{it} = B\ k_{1it}^{\delta}\ k_{2it}^{b}$

Cointegrating Equation	**Cointegrating equation 1**
Log(y(-1))	1.00
Log(k1(-2))	-0.74
	(-7.52)
Log(k2(-2))	-0.01
	(-0.07)
Constant	0.77
Error Correction	**D(log(Y))**
Cointegrating equation	-0.29
D(log(y(-1)))	-0.46
	(-2.41)
D(log(y(-2)))	-0.34
	(-1.75)
D(log(y(-3)))	-0.04
	(-0.18)
D(log(y(-4)))	-0.06
	(-0.35)
D(log(k1(-2)))	-0.27
	(-0.67)
D(log(k1(-3)))	-0.07
	(-0.15)
D(log(k1(-4)))	-0.02
	(-0.03)
D(log(K1(-5)))	-0.91
	(-2.29)
D(log(k2(-2)))	0.45
	(1.15)
D(log(k2(-3)))	0.37
	(0.52)
D(log(k2(-4)))	0.21
	(0.47)
D(log(k2(-5)))	0.62
	(1.53)
Constant	0.07
	(3.50)
R-Squared	0.74
Adjusted R-Squared	0.57